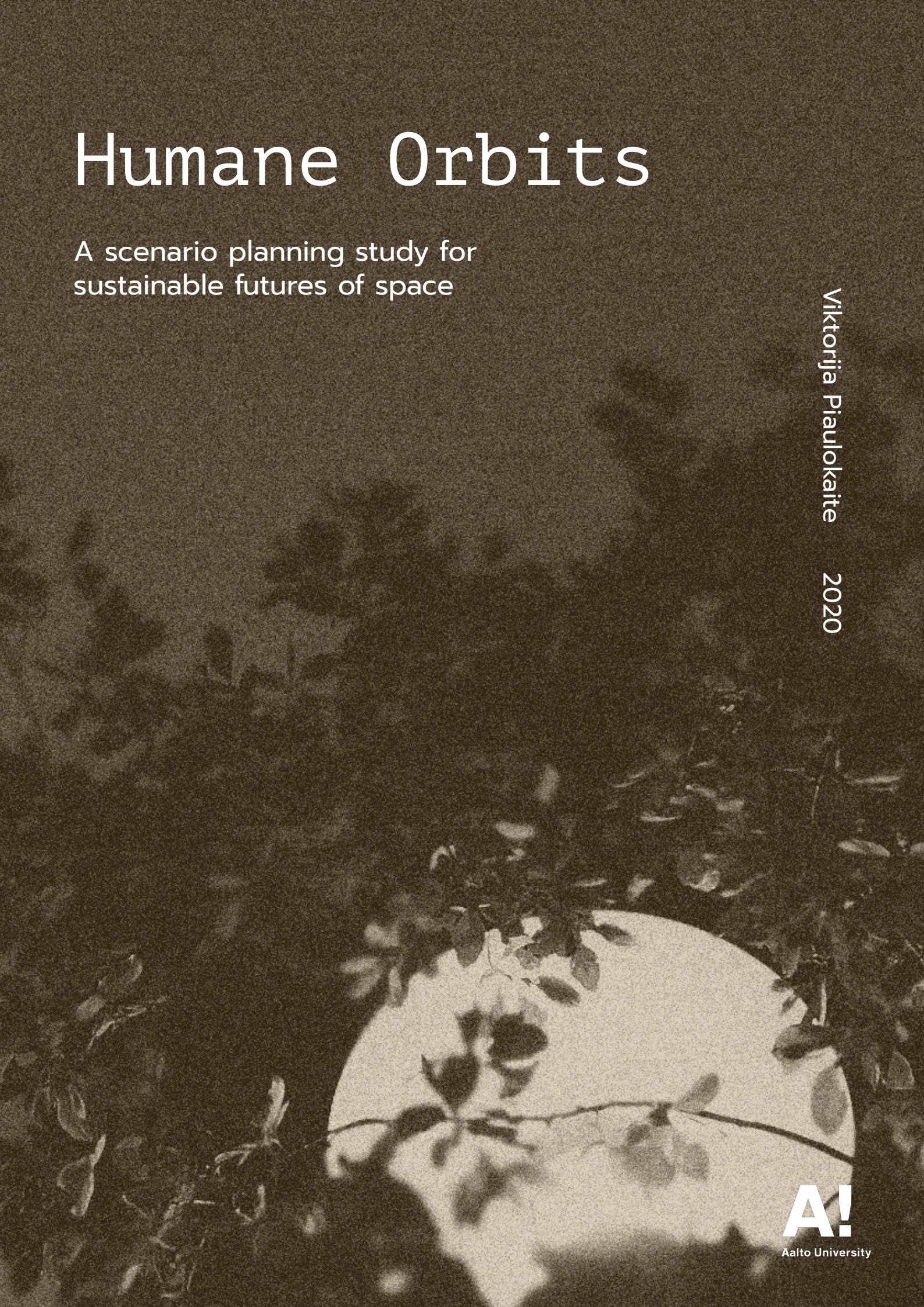
Humane Orbits

A scenario planning study for sustainable futures of space

Viktorija Piaulokaite

2020



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Humane orbits
A Scenario planning study for sustainable futures of space

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Abstract

Space, in particular, the low Earth orbit (LEO) is a very dynamic environment with an ever-increasing number of missions launched every year. This, just like on Earth creates a whole layer of traffic to manage in sustainable ways.

This study looks through transformative futures thinking applying scenario planning and Causal Layered Analysis (CLA) to learn the values that have been shaping the space activities in LEO, and how those values should evolve in order to drive sustainability.

Some of the questions asked in the study include future scenarios use in evoking discussion on the sustainable future of space among the decision-makers and space science and technology community. As well as, learning the underlying values that could shape the future of space in a sustainable manner.

This thesis study on sustainable space future has resulted in four transformative futures scenarios that serve as discussion prompts, and a policy reflection. It has been recognized that there is a need for holistic solutions to address the sustainability of space. This could be in the range from inclusive discussions on the values with which space domain activities are being shaped to proactive actions of space operators and focus on research and development of sustainable technologies.

Keywords: space sustainability, space environment, scenario planning, causal layered analysis, transformative futures thinking, low Earth orbit

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And most of all, my deepest gratitude to my family for unconditional support, love and encouragement in the steps I take.

Table of Contents

Glossary

Anti-satellite weapons (ASAT) - a system designed for the destruction or incapacitation of satellites for military purposes (Gottfried & Lebow 1985).

CubeSats - are a class of research spacecraft called nanosatellites. CubeSats are built to standard dimensions (Units or “U”) of 10 cm x 10 cm x 10 cm. They can be 1U, 2U, 3U, or 6U in size, and typically weigh less than 1.33 kg (NASA, n.d.).

Kessler’s Syndrome - is a theoretical scenario in which the density of objects in LEO due to space pollution is high enough that collisions between objects could cause a cascade in which each collision generates space debris that increases the likelihood of further collisions (Kessler & Cour-Palais, 1978).

Low Earth Orbit (LEO) - an orbit that is relatively close to Earth’s surface. It is normally at an altitude of less than 1000 km but could be as low as 160 km above Earth (ESA, 2020).

Orbital debris - is any man-made object in orbit about the Earth that no longer serves a useful function (ESA, 2020a).

Scenario Planning - In this study scenario planning definition is based on the Oxford Scenario Planning Approach (OSPA). Its’ one of key characteristics is an iterative process of framing, reframing, and reperception. Which represents an important shift in mindset from closed to more open and more flexible (Ramirez & Wilkinson, 2016).

The International Space Station (ISS) - is a space station that keeps moving in low earth orbit. It is habitable and the largest artificial satellite that can be seen with the naked eye from Earth. It acts as a factory, observatory, and laboratory (Economic Times, n.d.).

Acronyms

CLA - Causal layered analysis
OSPA - Oxford Scenario Planning Approach
LTS - Long-term sustainability
SDG - Sustainable Development Goals
TUNA - Turbulent-Uncertain-Novel-Ambiguous

Preface for COVID-19

This thesis is being written at an exceptional time of global uncertainty. In March 2020, the World Health Organization declared COVID-19 a pandemic due to the rising number of cases globally (WHO & COVID-19 Response, 2020). Countries have announced quarantine, with mass gatherings being restricted, schooling and work being organized remotely, borders being closed leaving airports empty as never before. Some have even called it the “Our Generation’s Great War” (Rapier, 2020). The significance of which may only be understood years, or even decades from now.

Without any doubt, this condition has placed the world at a crossroads. What would the world look like post COVID-19, what would the “new normal” be? All these questions have evoked discussions on the futures and life in general. I am truly hopeful that it will bring a new wave of exponential developments in medicine, extend knowledge of the virus, rethink ways of working, exploring our local surroundings, a closer connection to nature, and introspective view into ourselves.

At the time of writing, there are no specific vaccines or treatments for COVID-19 confirmed. However, I am really hoping that the active science community effort will succeed in developing effective medication. And I also want to express my most heartfelt condolences to those families that have been affected directly.

In this current context and conditions, I have been thinking hard about the futures, in particular the futures of outer space. In a long term perspective, going to space may even be the only recourse for the survival of our species. As well, there is a vast space environment surrounding us and outside our galaxy to explore. For future generations to be able to continue space exploration, it is in our hands and responsibility to give this opportunity to them. I wish this thesis will bring in some new perspectives on the emerging space sustainability subject, and more importantly, inspire many to bring space into broader conversations when talking about the futures.

Introduction

This chapter describes the context of the space domain, and its' some of the key pressing sustainability issues at the moment, that set the ground for this research study.

Introduction

Space-related activities have evolved dramatically during the last 60 years. By and large, they have caused an outsized impact on the global economy, social well being and sciences. Without even our noticing, modern lives have become closely dependent on space technologies such as weather forecasts, global telecommunications, worldwide banking systems, GNSS collision avoidance, and even satellite images to monitor our crops, water level, and pest infestations. Thus, space technology has been strongly weaved into our lives without us even noticing. This interrelation keeps growing involving satellite observation data as well in decision making and even in resolving the legal cases (EARSC, 2019).

This has been largely due to space becoming more accessible economically as the launch cost has been dropping by commercial launchers reducing the cost to the low Earth orbit (LEO) by a factor of 20 (Jones, 2018). As well, It is widely believed that for the first time in history we are at momentum at which space exploration may become the domain of private individuals. Since, private actors from the startups building CubeSats to more mature companies such as SpaceX providing the launching services and even planning a manned mission to Mars in 2024 (Musk, 2020). On the contrary, there are emerging views that the typical narrative of commercial space being a new phenomena is misleading. When looking at the history of American space exploration on a longer timescale, a very different history emerges—one in which personal initiative and private funding is the dominant trend and government funding is a recent one (MacDonald, 2017a). A. MacDonald (2017a) argues that early projects of privately built observatories in US, in the 19th century, by costs are equivalent to small robotic NASA probes built in current times.

Are we running out of space?

This question may sound controversial when talking about outer space. However, with the current pace of space industry development, it's a crucial risk that space may become less usable due to accumulation of the space debris. This issue would dramatically challenge the launch of the new space missions and the way space is utilized.

This thesis is an effort to create visions of the futures to strive for, the futures that take the current issues as an opportunity for transformation. If we don't transform, we create the used future (Causal Layered Analysis: Sohail Inayatullah at TEDxNoosa, 2013). Climate crisis is an example of the past futures that are happening at the moment. Thus, I personally believe that the time is now to shape future space visions to strive for.

Project deliverables

This thesis project consists of the following deliverables:

1 Future vision
Scenarios of futures of outer space in Low Earth Orbit (LEO).

2 Policy reflection
Reflection on how policies could be potentially shaped if certain future scenarios unfold.

Problem definition

Since the first spaceflight of Sputnik in 1957, the space activities and the accompanying legislation have worked relatively well. However, as the space industry is currently taking a rapid development pace, there arise new and complex problems that are challenging to define accurately. According to D. J. Kessler (former NASA scientist known for his studies on space debris), we are at what we call a 'critical density' – where there are enough large objects in space that should they collide with one another, they may create more numerous debris faster than they can be removed (Adams, 2015).

Such problems can be recognized as "wicked problems", first defined as "a class of social system problems which are ill formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing" (Churchman, 1967). Weeden (2014), a Technical Advisor from Secure World Foundation, has even described space sustainability issues even as a ''super wicked problem''.

Staging a thesis in this context, is an effort to approach the problems, understanding that it is too complex to solve completely.

Current state of outer space imposes some of the following issues:

- **Increasing number of orbital debris, creating collision risks for the currently launched objects and the future launches.**

  As of February 2020 space is occupied with 2300 satellites that are functioning (ESA, 2020b). According to AGI (2020) by 2029 this number may exceed 107,000 planned satellites. Such an exponential increase in the number of satellites launched, would raise the challenges of effective space traffic management and safety.

  Furthermore, there are about 22 300 debris objects that are regularly tracked by Space Surveillance Networks and maintained in their catalogue (ESA, 2020b). However, according to Nicholas Johnson, NASA chief

scientist for orbital debris “The greatest risk to space missions comes from non-trackable debris,” (ESA, 2020b).

The number of debris estimates by statistical models account for:
34 000 objects >10 cm
900 000 objects from greater than 1 cm to 10 cm
128 million objects from greater than 1 mm to 1 cm
Estimated by ESA’s Space Debris Office at ESOC, Darmstadt, Germany, correct as of February 2020

- **Gaps in the law concerning the ownership of the objects and resource extraction.**
  International legal framework on the use of outer space has been formulated for the states, meanwhile individual actors were not accounted for in the law.

Being a multifaceted problem it poses uncertainties that may evolve one or the other way in the future. Thus, future studies has been chosen for the study in order to explore different future scenarios that may unfold if certain decisions are taken.

Therefore, the research questions are defined as following:

How might future scenarios evoke discussion on the sustainable future of LEO among the space domain community and the decision makers?

What are the underlying values that could shape the future of space in a sustainable manner?

Project objective

Develop future scenario material that could evoke discussion on sustainable futures of space among the space domain community and the decision makers.

Target group

- Decision-makers shaping organizational strategies in the space industry organizations.
- Policy-makers shaping regulatory frameworks for sustainable space utilization.

Secondary target group

- General public - people who have general understanding and interest in space related matters.

Literature review

This chapter describes the literature review discussing the current state of LEO, space sustainability, legislative tools and some of the current initiatives in the space domain.

Literature review

On the Spaceship Earth journey

I would like to start this section with an excerpt from a Brundtland report written in 1987 to recognize the link between the space, sustainability, and our conscience:

> *In the middle of the 20th century, we saw our planet from space for the first time. Historians may eventually find that this vision had a greater impact on thought than did the Copernicus revolution of the 16th century, which upset the human self-image by revealing that Earth is not the centre of the universe. From space, we see a small and fragile ball dominated not by human activity and edifice but by patterns of clouds, oceans, greenery, and soils. Humanity's inability to fit its activities into that pattern is changing planetary systems, fundamentally. Many such changes are accompanied by life-threatening hazards. This new reality, from which there is no escape, must be recognized – and managed. (United Nations 1987, An Overview, para. 1.).*

Written more than three decades ago, this notion keeps its high relevance in shaping our understanding of sustainability and the human-self image within the larger context. It makes us question the norms of behavior and our impact on the Earth and outer space. It makes one realize how fragile the Earth and the outer space environment is.

LEO now

Since the Brundtland report, human activity has only kept accelerating, leading to the climate crisis we are currently in, and causing a number of new challenges in space such as orbital debris issues, endangering human safety both in orbits and on Earth. Space, in particular LEO, has become a limited resource, leading to the race to exploit potential outer space natural resources among other things.

In recent times, the sense of urgency for sustainable space activities has been increased by events such as Indian ASAT test in 2019 (Akhmetov et al., 2019), destruction by the Chinese authorities of their Feng Yun 1C weather satellite in January 2007 which generated more than 3000 additional long-lived fragments (Pardini & Anselmo (2009), an unintentional collision, in February 2009, between the Iridium 33 commercial communications satellite and the defunct Russian Cosmos 2251 spacecraft

On the right, figure 1, Apollo 8 astronaut Bill Anders' photograph of the first earthrise witnessed by humans (Anders, 1968).

(Parks, 2009). Such events place other orbital missions at risk and increase the need of maneuvering. For instance, in 2019 alone, International Space Station (ISS) conducted two maneuvers to avoid potential collisions with large debris tracked by the U.S. Space Command (USSPACECOM) Space Surveillance Network (SSN) (NASA, 2019).

The aforementioned issues can be summed up by Gerard Brachet, former chairman of the United Nations' Committee on the Peaceful Uses of Outer Space (UNCOPUOS):

> *'... our use of outer space since 1957 has been rather careless of its long-term sustainability. The situation might be compared to that of the 19th and 20th centuries with respect to maritime shipping and exploiting the oceans' resources where there was a wilful ignorance of the negative impact of pollution and a general blindness to the long-term effects of over-fishing' (Brachet, 2016).*

The setting in which space activities take place now are largely different compared to those in 1967. From space being dominated by two superpowers in the 1960s, to a space that is global and rapidly growing. Few studies produce future scenarios with computer models that suggest that the space debris population has reached a tippingpoint (National Research Council, 2011) it claims that collisions will increase in frequency even if there is no new space traffic (Liou & Johnson, 2006).

Space sustainability

Brundtland report is as well, known for the following definition: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland Commission, 1987). It is a well-known definition, which has become the basis of many sustainability practices. This section looks into how sustainability is defined for outer space activities, in particular LEO.

In the early days of space exploration building and launching previously non-existent space technology into space and having it function in the little known environment was enough of a challenge, without little concern to sustainability. However, as objectives of the missions were eventually becoming more ambitious, requiring the hardware to endure harsh space conditions for longer mission lifetime, the sustainability of the hardware came into concern. Newman & Williamson (2018) have called the sustainability of the hardware as the first manifestation of "space sustainability".

Martinez (2019), Executive Director of the Secure World Foundation, describes the key overarching challenges under the concept of "3 S" - Space Security, Space Safety and Space Sustainability. The challenges include: governance; information sharing; and maintaining strategic stability. Newman & Williamson (2018) suggest that in the context of space activities sustainability should mean that minimizing harm to the environment becomes part of the mission objectives alongside other technical and scientific goals. P. Martinez (2019) describes rather a macro view of sustainability being closely interconnected to security and safety, however, standing as a separate section containing a number of challenges. Meanwhile, Newman & Williamson (2018) looks closer into a mission design and describing sustainability within the process of mission design.

Scholars agree that sustainability issues in the space environment require collective action from the global community (Martinez, 2019) which resonates with the Outer Space Treaty, expressing the need for the states to follow the "principle of cooperation". Furthermore, concerning the space sustainability, most discussions focus around the LEO due to its urgency. However, some scholars are expanding this view beyond the LEO when discussing the potential risks to fragile space environments raised by human activity exploring other celestial bodies (Newman & Williamson, 2018).

How should humanity then manage outer space activities? Sustainability of space is has been described as *"super wicked problem"* (Weeden, 2015) which has no single answer, thus this study looks at different lines of thought, different issues that could add to addressing the issues. A super wicked problem is as well recognized by the following characteristics: time is running out, no central authority, those seeking to solve the problem are also causing it, policies discount the future irrationally (L. Kelly et. al. 2012). It should be noted that sustainability of space is mainly being discussed in space focussed discussions. For instance, in discussions on Sustainable Development Goals (SDG), space is more of a means to address sustainability on Earth, rather than an environment studied from a sustainability perspective.

Legislative landscape

Despite the rapidly evolving space domain, the law and regulatory framework has remained without the major changes keeping The Outer Space Treaty of 1967 as the main legal instrument for space activities. However, some prudent legal instruments have emerged such as, UN Space Debris Mitigation Guidelines, Space Security Index, and European Union's International Code of Conduct for Outer Space Activities. The major space agencies recognize the UN Space Debris Mitigation Guidelines as an example of 'best practice' towards limiting future orbital debris.

However, it is still falling short in adoption, as being voluntary guidelines and are not legally binding. Thus a number of scholars agree on the need to improve the regulatory frameworks in order to make outer space activities sustainable in the long term (Deva Prasad, 2019; Hoerber et al., 2019).

Current initiatives

The recent years have shown an increase in new initiatives concerning the sustainability of space. The initiatives stem both from intergovernmental organizations such as the EU - 3SOS initiative (2019), but as well as from private organizations - Space Safety Coalition (2019). The latter one indicates rather a new phenomenon on private companies taking a proactive approach in sharing best practices for the sustainability of space operations. This could indicate a growing awareness of businesses on sustainability in space activities.

As well, the adoption of the Guidelines for the Long-term Sustainability of Outer Space Activities (LTS guidelines) by the UN COPUOS has been one of the major milestones for the international space community (UNOOSA, 2019). This is supported as well by the emphasis on the growing importance of space safety and sustainability in space policy and diplomacy agendas (ESPI, 2020). Another recent development in space policies is the Artemis Accords (2019), which aims to establish a shared vision and set of principles on how to explore the moon. This is increasingly relevant in a collaborative manner of space exploration projects. Artemis Accords could be an example of shaping the norms of behaviour on the moon. This approach could potentially be transferred to other localities in outer space too.

Another initiative that directly targets space missions is The Space Sustainability Rating (SSR). It is set to provide a new, innovative way of addressing the orbital challenge by encouraging responsible behaviour in space through increasing the transparency of organizations' debris mitigation efforts. The SSR is being collaboratively developed by a consortium of entities led by the World Economic Forum's Global Future Council on Space Technologies (WEF, n.d.).

Furthermore, considering the technological developments in the debris mitigation, the European Space Agency (ESA) commissioned the very first orbital debris clean-up mission, called ClearSpace-1 (ESA, 2019).

Recent years initiatives show an increasing awareness of sustainability issues in the space domain not only among governmental organizations but also among private entities, as well as developments of new tools for sustainability management. This is rather a positive sign of developments paving a path for the bigger steps that are very much needed.

Figure 2, Poster series "Visions of the Future." (NASA/Jet Propulsion Laboratory-Caltech, 2018)

Need for miracles

Elkington (2020), also recalled as a Godfather of sustainability, discusses that what we need in the age of Anthropocene is miracles. What is a miracle in the current times? Fiction or reality? A writer Eisenstein (2018), shares a relevant definition for these times: "That's what a miracle is: Not the intercession of an external divinity in worldly affairs that violates the laws of physics, but something that is impossible from within an old Story of the World and possible from a new one".

This correlates well to the concept of reframing in Oxford Scenario Planning Approach (OSPA) which represents an important shift in mindset from closed to more open and more flexible (Ramirez & Wilkinson, 2016).

Building the narratives of the future could be this very beginning for the miracles to emerge. The importance of the narratives As Alexander Macdonald, space historian, has said in his Ted Talk [6] we need to tell stories that plant the seeds, if not necessarily for utopias, then at least for great new projects of technological, societal and institutional transformation.

Some of the examples of future studies in the space domain include scenarios for the space ecosystem future (A. Orlova, 2020), poster series called “Visions of the Future.”(NASA/Jet Propulsion Laboratory-Caltech, 2018), Participatory Scenario Planning for Indonesian Space Industry in 2025 (Agustan et al., 2018). The aforementioned scenarios have varying goals from being inspirational probes to strategic planning and exploring strategic perspectives.

Conclusion

To conclude, space sustainability is a recent and evolving concept within various contexts such as natural environment, science, business, policies and finally human conscience. The recent events of ASAT creating large number of debris are rather alarming, as well as legislative frameworks of Outer Space Treaties which hasn’t evolved since it was introduced first. However, the last year gave positive signs in proactive establishment of new initiatives both from the governmental side as well as from private institutions. Finally, to look for ways on managing space activities in sustainable ways is a global challenge which need collaboration, shared understanding and vision that could plan the seeds of “sustainability miracle” to happen.

Research approach

This chapter describes the research approach applied and gives an overview on the research methods applied.

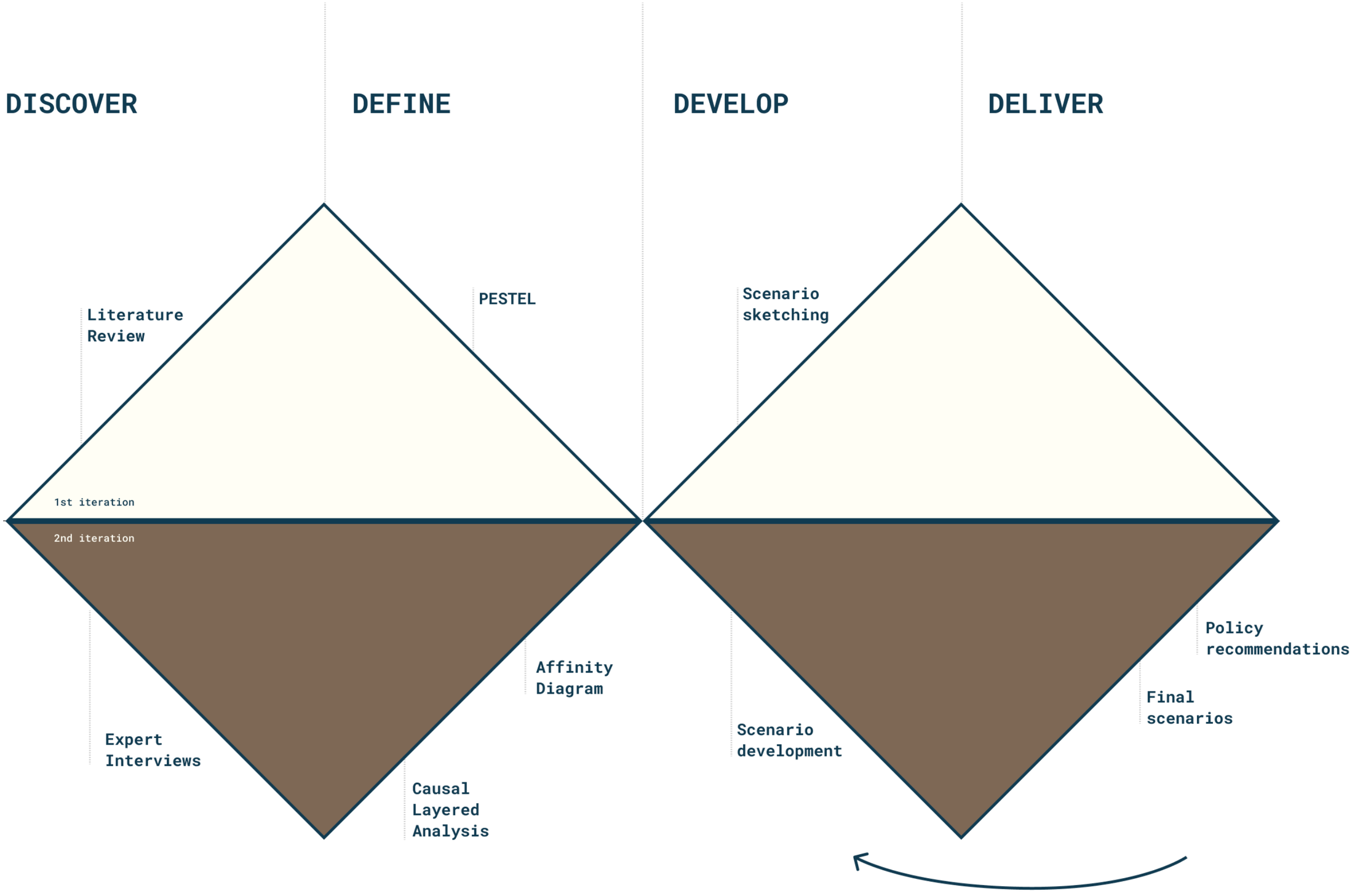


Figure 3, Project approach based on design process and the Double Diamond (adapted from Design Council, 2014)

Methodology

Research study follows design process based on the Double Diamond having distinctive phases of Discover, Define, Develop and Deliver (see figure 3). Methodology consists on a set of qualitative research methods that enable divergent thinking and convergent thinking depending on the stage of the process. Some of the methods include: Literature Review, PESTEL Analysis, Expert Interviews, Causal Layered analysis and Scenario Planning.

In this study, literature review together with PESTEL Analysis have served as a foundation for the initial set of scenarios, which expanded up to 16 initial sketches. As it is common to design process, this study has followed two iterations, where the results of the first iteration have been further refined. After evaluating the results of the first iteration (scenario sketches and initial scenarios), the objective in the second iteration has been to better understand the underlying causes of the phenomena that shape space activities and potentially the futures of sustainable space.

Finally, second design process iteration has resulted with deeper insights and better understanding of the underlying causes, worldviews and values that are shaping the space activities. The insights have been transformed into a new set of future scenarios. The final scenarios have been used to reflect on the current policies and envisioning what direction policy development process may take if certain futures unfold.

Scenario Planning Approach

Influential players in the world of business and policy, such as the Secretary-General of the OECD, have shared that scenario planning "is needed more than ever." (Wilkinson & Kupers, 2014, quotation on the book cover). Scenario planning is a methodology that uses the human capacity for imagining futures to better understand the present situation. Thus, possibilities for new strategies are opened up, the link between the strategy and futures is being created throughout this process. Scenarios can help individuals, communities, corporations and nations to develop a capacity for dealing with the unknown and unpredictable, or the unlikely but possible (Merrie, 2018), which is critical in order to manage LEO in sustainable ways.

Furthermore, the relevance and applicability of scenario planning and other techniques to envision futures is shown by its increasing use by governments so as to support policy making in the fields such as natural resource management (Evans et al., 2013; Peterson et al., 2003).

Across a wide range of questions, scopes, and timeframes, environmental futures can provide decision-makers a sense of upcoming changes in the environment, thus supporting development of proactive, rather than reactive, strategies (Gibbs & Flotemersch, 2019). It is important to note that scenario planning is not aimed at predicting the future, but rather at exploring the possibilities.

The domain of futures studies has its roots in the military setting emerging after the World War II (Margolin, 2007). The early attempts applied modeling techniques to create future scenarios, which have been further evolving throughout the decades and applied in new settings dominantly in corporate strategy.

Scenario planning has been chosen to study the futures of the LEO, due to its ability to generate strategic conversations. Wilkinson and Kupers (2014) noted that perhaps the greatest power of scenarios, as distinct from forecasts, is that they provoke rather than suppress conversation and, in turn, enable new common ground to be forged in a process of sequential consensus building that uses the efficient mechanism of storytelling to forge more shared and systemic understanding. Scenario planning achieves this by applying an interdisciplinary approach to generate insights and reframe understanding of the issues. Space sustainability, being identified as a super wicked problem requires systemic approach, involving different stakeholders.

Scenarios are appropriate when a long-term view is required, when there is great uncertainty about the system in focus, when unquantifiable factors need to be considered, when great breadth is desired, and when information has to be organized from a decision-making viewpoint (WWAP, 2012). "Design for future needs" (2003), a research funded by the European Commission , has shown that design techniques for envisioning the future support decision-makers' foresight planning and policy work. Thus, nurturing the following abilities:

- The ability to generate many responses (as designing multiple futures rather than one).
- The ability to crystallize and shape the response in a tangible form that speeds up the decision process improving communication with important non-specialist external stakeholders and the end-user.
- The ability to integrate critical foresight information when designing products or services with a longer lifespan.

Scenarios based on their purpose are classified in various typologies. However, there is no common agreement on the types. This study follows a typology described by Börjeson et al., (2006) reflecting on the following types: possible, probable and /or preferable futures (See figure 4). This typology is quite commonly reflected by different authors including Henchey (1978) who first coined it, Amara (1981) and Voros (2001).

Börjeson describes the subcategories of scenario types. This study follows a normative - transforming type of scenario (See figure 4). This type of scenario addresses the following question: How can the target be reached when the prevailing structure blocks necessary changes? (Börjeson et al., 2006). This type of scenario was chosen based on its' purpose to set certain values (in this case sustainability) as a target and identify the transformations in the current world that could lead towards the targeted futures. In transforming scenario studies, the starting point is a high-level and highly prioritized target, but this target seems to be unreachable if the ongoing development continues (Höjer, 2000).

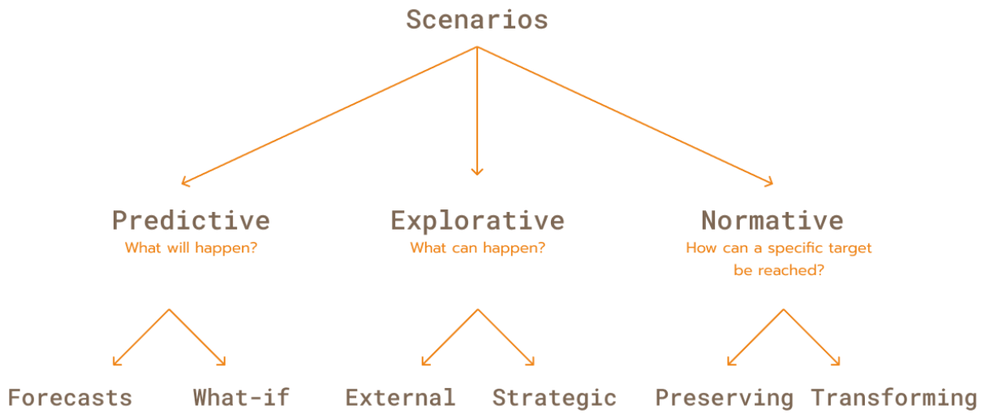


Figure 4, Scenario typology with three categories and six types (adopted from Börjeson et al., 2006)

Epistemological perspective followed in this study is cultural-interpretative which emphasizes on understanding, negotiating and acting in order to achieve a desired future (S. Inayatullah, 1990). This perspective has been expressed by the choice of techniques applied in this study such as Causal Layered Analysis (see it described in the page 36) so as to support transformative future scenarios building.

Novel developments often take place in conditions that are turbulent, uncertain, novel and ambiguous, also known as TUNA conditions (Ramírez and Wilkinson, 2015). The current developments in LEO, could be described as such, as New Space developments are taking place, legal frameworks are getting outdated and high political polarization is present (see more details in the section PESTEL Analysis).

It has been proposed by Social scientists Emery & Trist (1965) that in "turbulent fields" (TUNA conditions) strategy requires collaboration and realignment of values. Thus, the question comes what are the values on which to build space activities. Scholars from different disciplines agree on the need of space activities to be built on the values that recognise and respect fragile space environment (Newman & Williamson, 2018; Roberts, 1997).

Next to the values, it is helpful to look into the motivations that are driving space exploration. Historically looking into the past space exploration endeavours, economic space historian MacDonald (2017a) argues that there are two key motivations to space exploration that are intrinsic motivation and signaling motivation. In the future scenarios presented in this thesis it is questioned whether the same motivations will persist or will evolve eventually and how these motivations could be in line with sustainability values.

PESTEL Analysis

Operational environment of space activities is rather complex, made of a number of different factors and trends. To gain a better understanding of the macro environment-factors affecting space activities, "PESTEL" framework has been applied. Typically it considers the following aspects: political, economic, social, technological, environmental, and legal. This study follows it with a slight variation having the following categories: Science & Technology, Legal & Politics, Ethics & Environment, Business & Welfare, Societal. The type of categories stem from the phenomenons identified, emphasizing aspects of it such as science, ethics and welfare. As well, categories of legal and politics have been merged as being closely tied in this context.

Causal Layered Analysis

Causal Layered Analysis (CLA) is a technique to help to enable transformative futures thinking. CLA was first introduced by S. Inayatullah in 1998 Since then it has been further evolving and being applied in various studies. In this study, it has been chosen as a foundational technique for scenario planning. In particular it has been selected as it focuses beyond the surface, learning the myths and values that have shaped the issues allowing for a range of transformative actions. Some of the benefits applying CLA as described by S. Inayatullah (1998) include:

1. Expands the range and richness of scenarios;
2. When used in a workshop setting, it leads to the inclusion of different ways of knowing among participants;
3. Appeals to and can be used by a wider range of individuals as it incorporates non textual and poetic/artistic expression in the futures process.
4. Layers participant's positions (conflicting and harmonious ones);
5. Moves the debate/discussion beyond the superficial and obvious to the deeper and marginal;
6. Allows for a range of transformative actions;
7. Leads to policy actions that can be informed by alternative layers of analysis;
8. Reinstates the vertical in social analysis, ie from postmodern relativism to global ethics.

CLA attempts to deepen and widen understanding of the issue by including various types of knowledge. In the process, it builds a basis of knowledge on the different layers of the issue. The layers are as follows: The Litany, Causes, Worldview, Metaphors and Myths (Inayatullah 2004; See figure 5). The method helps to build understanding on the different layers of the issue studied. After moving from the deeper layers of Metaphors and Myths all the way to The Litany a holistic in depth understanding of the issue is being created. The new reframing of the issue can be well reflected within new policies and initiatives to stimulate transformation.

The knowledge for CLA can be created in various approaches such as interviews, workshops or games. In this study, the layers have been studied by building up the knowledge base from the expert interviews.

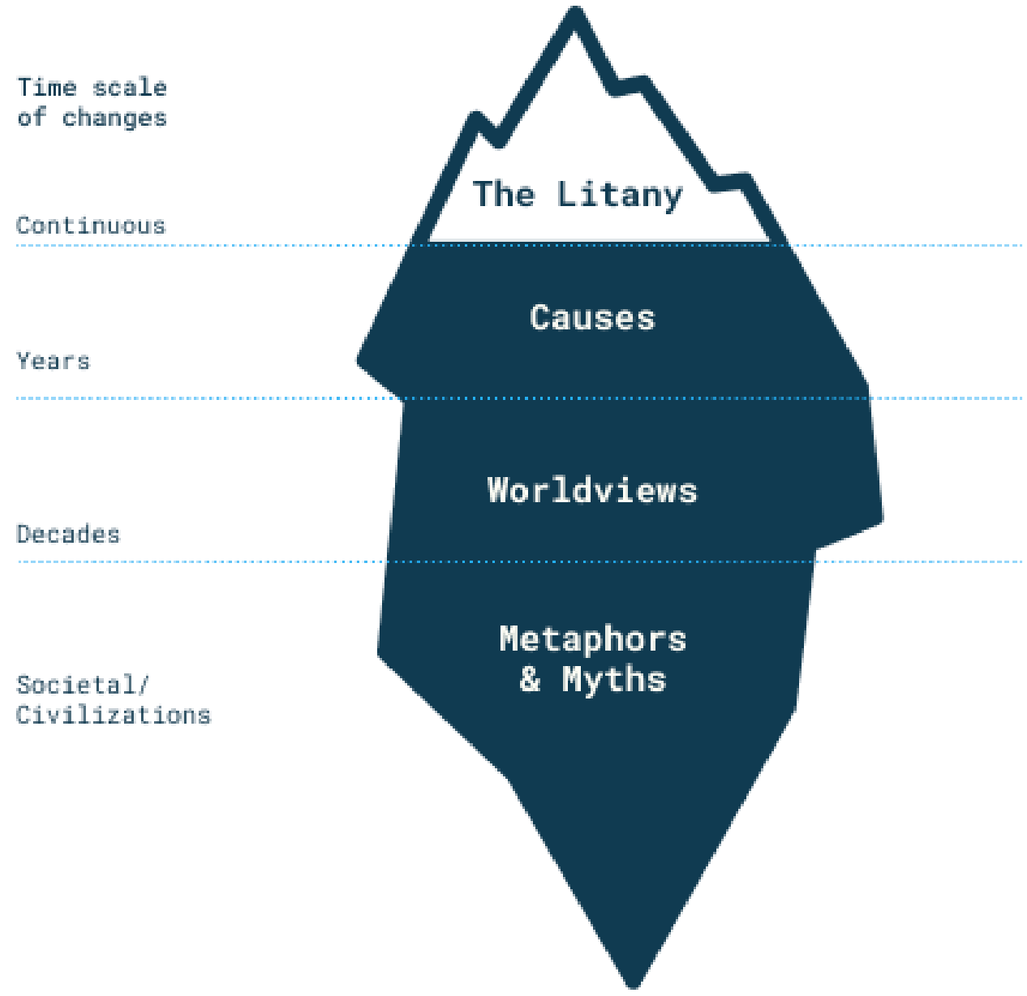


Figure 5, Causal Layered Analysis (CLA) framework, (adapted from Inayatullah, 2004).

Expert interviews

Data collection for CLA has been done by applying an expert interview method. This method has been chosen on the basis of acquiring the knowledge directly from the people with the first-hand experience in the researched subject. In a study by Bogner et al. (2009) expert is defined as a person with technical, process and interpretative knowledge in relation to their areas of expertise. Experts in this study were identified as people directly involved with space activities professionally, or people with academic knowledge in the space science and technology field. The experience of interviewees has varied from young graduates to people working in the field for decades. This has helped to gain a perspective of a young generation of future decision-makers as well as a generation of experts that is currently shaping the policies.

Considering the current pandemic restrictions and recommendations to work remotely, design research methods have been facilitated online. This has affected initial plans to facilitate on-site workshops for the knowledge creation and the feedback rounds. However, such a situation has opened an opportunity to connect to the global expert community for this study. This has enabled rather in-depth interaction with every research study participant, which might have been hardly possible in a group setting.

The study has conducted 11 interviews. The interviewees were selected based on their active involvement in space activities with solid years of experience as well as young graduates. This study aims to build a holistic view of the futures including various perspectives. Thus, it aimed for a diverse group of the interviewees within the space field and outside of it. Interviewees included scientists, environmentalists, lawyers, film director and anthropologist working, or previously worked in the space domain.

To conduct the study, there have been sent 30 invitations to participate in the master thesis research study on sustainable space futures. Out of this number, 11 invitees have shown interest and agreed to proceed further to the interview stage. This makes it a bit more than 30% success rate, which is relatively high and could inform us of the relevance of the topic. It is notable, however, that initially the research has been formulated as an open question survey in a written format and the response rate has been low, not resulting in the responses. Thus, there has been an alternative proposed to do an half an hour, Structured interview facilitated on the Zoom platform or phone call. This has significantly increased the success rate of the interviews. In this study, this clearly shows preference to the videoconference rather than a written format survey.

After the first interviews, there have been few adjustments done scoping down the interviews to focus on LEO. This was after recognizing the number of issues that go beyond LEO, and are out of the scope of this study.

CLA based questions used in the interviews:

Litany
1 What are your first thoughts about sustainable space?

Social Structural
2 In your opinion, what sustainable practices that we need to adopt and the challenges we face?

Worldview/ Discourse
3 What does space exploration mean to the space domain community?
4 What ethical guidelines are still required? Who has control to change things? Who is helpless?

Myth/ Metaphor/ Symbol
5 What stories do space domain community members tell about themselves? Who are the luminaries and why?
6 Is there a book/song/ or movie that captures what you have been describing in the previous questions?
7 How do you see the future of space exploration and ideally what would you like it to be?

Data analysis

This chapter describes the analysis and results of different methods applied in this study.

PESTEL Analysis

The phenomena have been identified based on the literature review and the authors personal observations of recent discussions in the space community.

The phenomena identified are rather diverse within the categories and vary on different levels from the mission design to the overall state of the orbits. As well, some of the phenomena may be seen as variables that may evolve in various ways in the future and are later applied in scenario sketches.

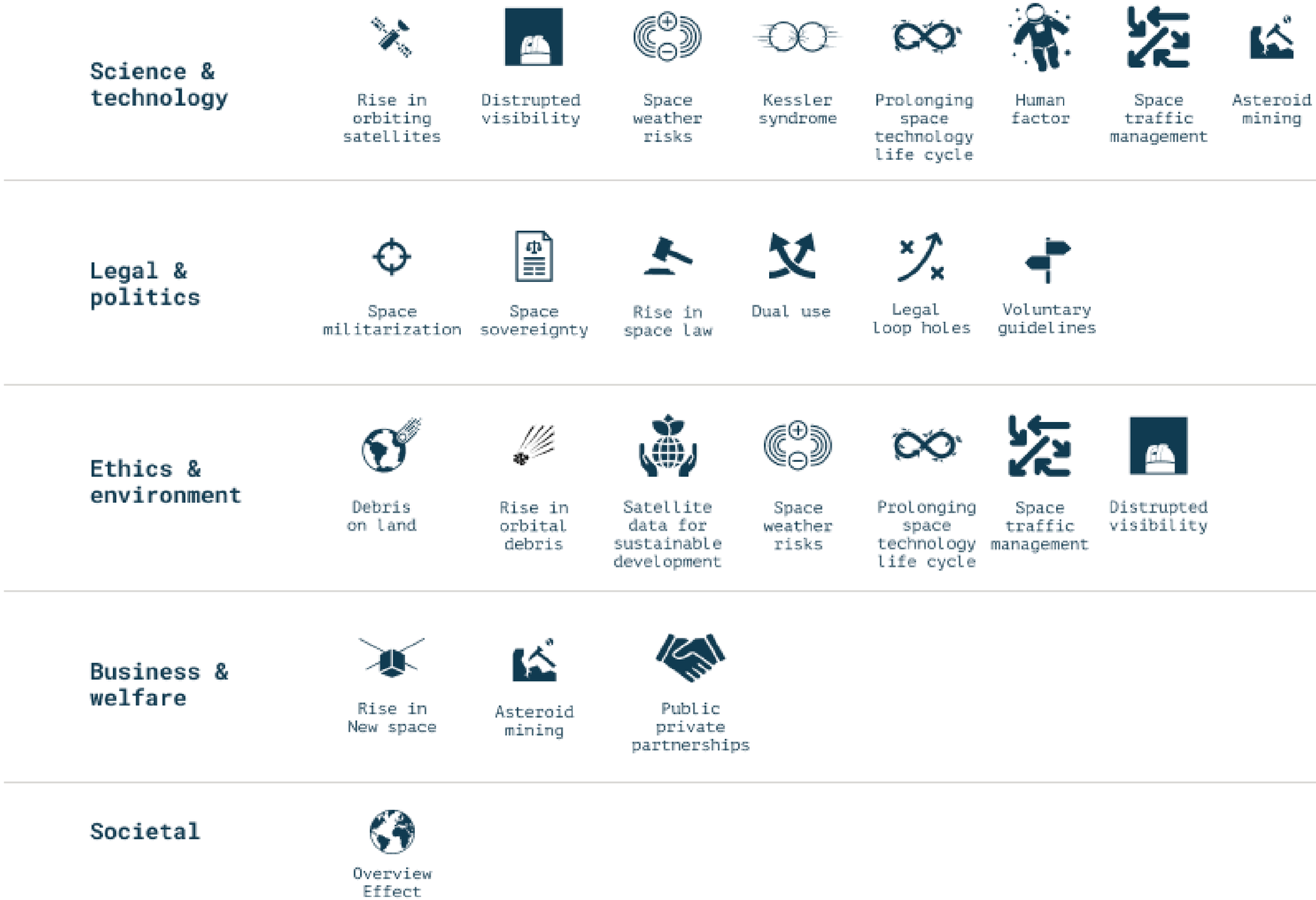


Figure 6, PESTEL Analysis

Science & Technology

Space domain has been experiencing a rapid increase in the number of small missions and nano satellites. This creates a whole new layer of traffic to manage. If not managed well, an increasing number of actors may create risks of collisions, or even the Kessler syndrome, potentially making certain orbits unusable. Space environment is naturally very harsh, raising the risks for the missions. For example, in the event of intense coronal mass ejection, electronics may be severely affected. Technological developments also open opportunities for developing in-orbit servicing. Furthermore, sustainable technologies, such as plasma brake for deorbiting, or E-sail for long distance missions, have high potentials for increasing the missions' lifetimes.

Legal & Politics

Legal frameworks regulating space operators behavior are predominantly of a voluntary nature. Outer Space Treaty remains the basis for the norms of behaviour. However, political polarization on Earth may have the potential of raising tensions in the orbits as well. Potential dual-use technologies are among the risks that may disturb the peaceful use of outer space. Furthermore, recent ASAT tests show that different nations are building such capability, increasing the tension in the orbits. Finally, the legislative frameworks introduced thus far implicitly assume all the space actors to be nation states. Thus, there exist legal loopholes for the New Space operators. A few individual countries, for instance Luxembourg, have introduced legislations that define the exploration and use of space resources.

Ethics & Environment

Ethics in space is a subject more frequently discussed in the context of planetary environment, on how it should be studied, to respect the planetary environment and potential life organisms. However, ethics in LEO is slightly more of a different nature, and predominantly led by the UN. One of the key principles is the peaceful use of outer space. However, how we treat LEO environment in the context of a booming number of satellites is rather complex ethical challenge, as it concerns the behaviour of an ever increasing number of actors, acting under different states, and even a few non-state players. Finally, surface impacting space debris is another challenge which poses the risks for the natural environments on Earth. For instance, recently there has been a case of toxic material splash-down in the Arctic waters, raising serious ecological concerns.

Business & Welfare

Space activities and space based services provide a vast business opportunity. From telecommunications to the space tourism, broad possibilities run the whole spectrum. Already now many of the services used daily are space based, for instance, banking, collision avoidance systems, and the internet. Copernicus Programme is another example, offering open source satellite data of Earth Observation missions, courtesy of ESA's Sentinel satellites. This has opened up opportunities to invent meaningful uses of satellite data to support our life on Earth. Finally, services such as launching and other infrastructures, that have been mainly provided by the governments, are starting to be offered by the private companies such as SpaceX. Another trend is the growth in the public-private partnerships, seen in many upcoming missions being planned, for example the ClearSpace-1 mission, or even the Mars landing.

Societal

Human understanding of space goes back to centuries or even thousands of years. It's our surrounding environment evoking curiosity of the vastness of space, stars and constellations reflected in the literature and culture, studied under Astronomy science, from observatories as well so called 'lighthouses of heavens'. This progressed forward to actually physically reaching the space with the first rockets and Sputnik in 1957. In few years, this gave humanity the first look at ourselves, the Earth as the "Earthrise." picture was taken. This has been a mindset shifhting moment. Humanity is already a spaceship orbiting among the other planets. This as well brought an understanding of human as a race without the boarders. Finally, space is a source of aspirations and curiosity and developments in space technology is an example of it.

Affinity Diagram

Expert interviews have generated a pool of qualitative data. For the data analysis Affinity diagram method has been applied. This method was chosen as it is well suitable for analysing large amounts of qualitative data in a structured and organized manner. In this study, the affinity diagram helps to identify emerging and dominant themes based on the expert views from the interviews.

First, in data analysis, the author writes affinity notes. Digital platform Figma has been utilized for this purpose. Then affinity notes were organized by the interview questions. In some studies, researchers avoid clustering data based on the questions. However, in this study, questions are based on CLA hierarchy and are formulated in a way so as to cover aspects on each different level. Data analysis has been conducted by the researcher individually, based on the consideration that all the interviews were conducted by the author and there is no workgroup of this thesis. Though it is a common practice to conduct an Affinity Diagram in a group or project team.

The dominant themes and clusters

Litany layer describes the first thoughts, associations when thinking of sustainable space. First, there is a clear division between the interviewees - ones who recognize space sustainability as a concept within space domain; ones who do not recognize space sustainability as a concept within the space domain. Furthermore, there has been rather a large cluster of views on environmental aspects of space sustainability. As well there has been expressed a normative perception on the necessity of sustainability.

Causes layer discusses the practises that need to be adopted and the challenges for it to happen. Dominant clusters in this layer discuss concerns on information sharing for transparency, sustainable technologies, and the attitudes of the space operators.

Worldviews layer goes deeper into learning the attitudes and the motives that are shaping the behaviours of the space operators. Some of the dominant clusters include ‘’personal interests’ as a driver, and the need for cooperation.

Metaphors & Myths layer is the core underlying layer that tries to understand the deepest motivations, narratives shaped hundreds years ago that are alive in our conscience and decision making. The dominant clusters are “humane space”, “everyday life”.

Finally, the analysed data has been applied in the CLA framework (see Table 1), as well as listing the currently applied or potential solutions.

Layer	Meaning	Sustainable futures of space Analysis	Solutions at each level
Problem	Official unquestioned view of reality, surface issues.	LEO - a finite resource, is poorly managed causing serious environmental, technological and human safety risks.	Accept the risks, follow the recommended guidelines.
Causes	Systemic causes & explanations (social, technological, historical, environmental, political, economic).	Low transparency of space activities, makes it challenging to manage space traffic.	Tools providing data on risk of collisions (e.g. ASTRIAGraph and LeoLabs). However, these tools directly depend on space operators’ willingness to share the data). Introduce legally binding tools.
Worldviews	Deeper social & cultural processes.	Largely private interests driven behaviour. Dominance and pride. Fragmented/polarized international community. Low trust and motivation in data sharing for space traffic management.	Inclusive dialogue and cooperation. Sense of unity and stewardship.
Metaphors & Myths	The unconscious emotive dimensions of an issue. Stories & symbols.	The everyday life of humane, inclusive space. Intrinsic motivation.	Including space within the planetary boundaries concept. How not to repeat the mistakes done on Earth?

Table 1, CLA based on the insights gained in the expert interviews.

Ecological system perspective

- Ecological sustainability perspective
- Affect on people on Earth and the natural environment
- Finite resource
- The environment
- The space trash, debris, everything it's a huge problem
- Problems such as environmental pollution from propellants
- Need for a system like orbital carrying capacity and use that as a way to inform us of environmental impacts

People-driven demands

- Current situation dictated by people's activity, but not from an environmental impact perspective
- How not to repeat mistakes we had on Earth, from thinking that Earth resources are unlimited, “there is always more”

A must

- Ability to continue activity in a long run
- In everything we do we have to think sustainability
- A capability that should be accessible and renewable
- Any normally running activity must be sustainable
- Space is meager resources, until we are limited by technology
- Continuing use in the long term
- Necessary to ensure the future use of space

Economical aspect

- Cost of space activities should be affordable to be sustainable in the long run

Circularity aspect

- You don't waste anything, you reuse everything, you circulate everything
- Design for closed-loop

Safety aspect

- Safety of running activities in space
- “Sometimes very seldomly, there are some accidents like that and there are rumours that some horses have been killed in a farm, because of part of a booster falling down.”
- The threat of militarization would make it challenging to maintain sustainability

Sustaining species

- In the very long run, mankind should move into space to make our species truly sustainable

Traditional ecological knowledge

- Traditional ecological knowledge as a source of principals that could be applied in space

Novel in space context

- Sounds strange because usually talk about sustainability as an Earth concept
- Is there sustainability in space exploration?

Opportunity

- Opportunity for both being able to design more complex missions and produce sustainable Earth spin-offs
- Many of the concepts, which will need to be developed for space, would also serve as a solution in sustainable applications on Earth.

Figure 7, Affinity Diagram, insights clustered based on the CLA layers

Causes

Safety

Human perspective is important, so that things must be safe”

Passive in contributing

“people like those ideas, but when you ask them to contribute to that, then they don't, they're not so they're reluctant to do that everybody wants to wait for somebody else to do it first and that sort of thing”

“A lot of people don't want to do that because they feel maybe it's sensitive or it's a security issue, or they want to get paid a lot of money for the data that they have.”

Space should be more inclusive - “Space for all, that kind of paradigms should be adopted”

“people aren't really understanding that if space is going to be sustainable, then we need to do things that make space more transparent”

There is a need of regulations from a neutral body

Measurements is foundational

“Measurements is foundational”

Sharing of data is challenging

Three kind of ways to measure of the sustainability is transparency predictability and accountability.

Technological sustainability

Adopt propellantless way of moving in the solar system such as electric solar wind sail

Lower the cost of access to spacesteam balloon. e.g. using steam as a lifting gas of a balloon to lift a rocket into the stratosphere and launching from the stratosphere.

Design for in-situ maintenance and repairs

Adopt plasma brake for deorbiting

Space as a huge “flea market” - nothing is ever thrown away, everything you can reuse.

Design for in-situ resource utilisation and transformation

“I see sustainability of course it's always a mindset, but also it's at the bottom of it all, it's a technological challenge.”

“confined space”

Complex digital tools are needed to be able to design sustainable missions

Worldviews

Self interests

Some people are still using the term colonisation which I think is completely wrong for a variety of reasons.

National pride

People just say “oh well if it's legal then I can do it.”

“I see the risk that there will be a race to the bottom in terms of standards (like flags of convenience) in order to benefit from national regulatory systems which did not protect the environment or workers' rights.”

Tone of domination is not the right tone

To military - means defence

To governments - means soft power

“Signalling” as a motivation

Human ethics before interplanetary ethics

The planetary protection is an important thing so that we don't contaminate Mars, especially before we have studied if there is life.

This century Ethics in space will mean human Ethics

Issue with life on Mars, and planetary protection guidelines. Pretty sure Mars is a dead planet, but cannot prove the negative. Disregard that, planetary guidelines must be followed.

Ethical conventions have been respected pretty well

Let’s say we find life on Mars, it will require quite a lot of new ethical thinking about do we even have the right to go to Mars etc.

Intrinsic motivation

Natural need to explore, would be very strange if we stayed in one place

In space you are a “citizen of space”

It’s space that is changing us

Intrinsic motivation

Getting outside “bubble” / cooperation

I believe that the space industry community cannot afford to remain in a bubble but also has to look at society as a whole.

United Nations Office of outer space activities and Sustainable Development Goals

Socio economic development

In the long run need a global approach

For developing new standards, bottom up approach will be needed involving all the stakeholders.

The state of societies in terms of commitment to the rule of law and human rights is varying globally, which would require change to happen in different ways.

“So what I believe what might happen is that satellite operators might start voting with their feet so to say that they simply exit from those altitudes, that are layed with debris.”

“Let's say a sustainable human life in space I think it requires cooperation cooperation and cooperation.”

“The international community is difficult to agree even on some basic things, let alone more abstract things like space debris.”

Humane

“I think space ethics also will be about growing up more and more, realising, things that unite us and forgetting the things that divide us because in space they don't really matter anymore.”

Realistic optimism (proving retrospective view to the past)

A connotation of ownership versus being a steward or custodian.

Politics of debris on land

“And then during the Soviet times Stepe it was full of these rockets nobody touched it because it was not free you know that was communism. And then after the communism collapse, people began to exploit this because it's titanium and aluminium it's really and some gold also.”

Balanced pace of scientific and economic developments

To scientists - could be scientific enablement and search for extraterrestrial intelligence and life.

The economic growth and requirements of science instruments growth should be somehow balanced.

Sustainability of science. If the new instruments are always more costly than the previous then that cannot continue forever so and at some point, it causes a collapse of the whole science domain then.

Metaphors & Myths

Humane space

Inclusive	Approach it as a humanity
Takes into account the opinions of indigenous people	Beneficial for all, inclusive
Communicate about these (space provided) opportunities and make everyone feel included	Beneficial for all, inclusive
“Many actually astronauts and cosmonauts coming down from a long stay in the International Space Station they have this “humble thing”. It's not religious, it's more like, “yeah, we are small”, you know.”	

Everyday life

Space as everyday life	That was really about the sustainability, what do you do if you only have this one big room, where you have to survive on Mars. Like, he started growing potatoes so he would have something to eat, he was calculating carefully how he would recycle everything in a sustainable way. I think that was the most realistic thing that I have seen the space in both books and movies during the last 10 years.
Less of a nationalistic thing	The Martian movie
The benefits have to be made clearer, visible	As a way of solving our problems here on Earth
“I would like to see more humans in space”	

Technological solutions

People might start to favour, very low orbiting satellites, as they are naturally immune, don't produce orbital debris.	Electric propulsion systems that run on oxygen, or atmospheric gases.
Using plasma brake	Design for demise (D4D) principle
Issue with Titanium	

Mood

Something with sad sadness or melancholy in it because I think too many people are just doing whatever they want, without considering the consequences, including unintended consequences on others.
very hopeful, very bright

Expert interview results

Expert interviews have shown diverse perspectives and opinions on the topic of space sustainability. It has revealed that to manage human activities in space in a sustainable manner, a holistic and proactive approach is needed. This section describes the dominant themes as expressed by the interviewees and some of the aspects of holistic approach. The themes are described by the quotes expressed by the interviewees and brief summaries of the themes.

By the most interviewees, sustainability in space activities has been associated with the ability to run activities in a long run and identified as a necessity. The first associations when hearing the term sustainable space have varied, describing environmental, economical, and safety aspects, with environmental aspects being dominant. Some interviewees as well have shared that it is unusual to hear the term sustainable space, as sustainability is being more associated when discussing the issues on Earth. This section describes various themes identified in the interviews.

The critical state of LEO

"Too many people are just doing whatever they want, without considering the consequences, including unintended consequences on others."
Moriba Jah

"I think [commercial actors] are recognising that these security concerns in space, things like destabilised space, could absolutely affect their investment and their ability to use space. And so, there starts to be more of — I wouldn't say interests — but awareness that they need to know about these issues, and maybe give input about it as well."
Victoria Sampson

"In space, sustainability is the terminology that's being used instead of considering spaces and environments. If you look at space as an environment, you have a different kind of set of moral obligations towards it."
Alice Gorman

All of the interviewees have recognized a critical state of LEO. The number of satellites in orbit is exponentially growing, and is projected to continue, resulting in densely occupied orbits. Furthermore, the manner in which space activities are currently being carried out is rather disorganized, and largely driven by the private interests. However, there has been some evidence of emerging awareness from private companies, as they are starting to recognize the need to protect their investment.

Polarization

"It's been really eye-opening that the international community does not agree on what the space threats are."
Victoria Sampson

"It's the spacefaring nations that get control of the discourse, and the decision making. And this means that there are massive blind spots, in terms of ethical behaviour in space."
Alice Gorman

"Science fiction writers have written about a future where poor are left on earth and the rich save themselves and have lives in orbital habitats and on the planets. Space travel widens the gap between rich and poor on Earth. And that's pretty much where we're heading right now, unless we do something about it."
Alice Gorman

"I think challenges are that people like those ideas [of ways to measure sustainability], but when you ask them to contribute to that, then they don't. They're not so [eager]. They're reluctant to do that. Everybody wants to wait for somebody else to do it first, and that sort of thing."
Moriba Jah

The aspect of polarization has been recognized on different levels. Few interviewees have recognized that there is a lack of shared understanding of some fundamental things concerning the sustainability and safety of space. This leads to a very challenging situation for making any decisions on an international level, since there is no common ground of understanding. One of the interviewees has shared that there has been a recent initiative on setting the same language, establishing definitions on some of the fundamentals, which may at first look like a step back. However, it may be what is actually necessary to start with in order to have a shared understanding and agreement. Furthermore, once there is an agreement on the issues and potential solutions, there has been recognized a passive attitude to take any action. Such dynamics create a rather polarized community driven by private interests. There is also a growing recognition that the space industry community should draw efforts to have a good rapport with the local communities where the companies operate.

Need for inclusion

"We have to protect everybody's rights right now, not just a small elite's. We have to see the full picture and work on all pieces of the puzzle at the same time in order to create a more just society. The space industry has a role to play in this, too."
Stefan Kirchner

"There is so much that we can learn in space that can then help us here on Earth. Some of it we can anticipate, such as sustainability in space translating to sustainability on Earth... But we need to communicate about these opportunities and make everyone feel included."
Anne-Marlene Rüede

"We should look at things like traditional ecological knowledge, and respect each other's cultural perspectives, and these sorts of things, and have an inclusive dialogue. I don't think we have an inclusive dialogue about exploration, people just say, 'Oh well, if it's legal, then I can do it.' "
Moriba Jah

"In ethical terms, it's based on the assumption that certain spacefaring nations can act on behalf of all humanity. And that assumption is simply not true. So I think that's something that needs more work as well."
Alice Gorman

There has been recognized a need for inclusive dialogue, having the opinion of indigenous communities. Without space being inclusive, the rights of more fragile communities are disrespected. For example, such endeavours could contribute to the dialogue with traditional ecological knowledge. As well, one of the interviewees has shared that inclusion and proactive communication could help communities to understand the opportunities and the benefits of space exploration, in particular the potential of adopting space sustainability solutions on Earth.

Perception of space

"It would be very strange, if we just stayed. If you have a big home, and you only stay in one room of the home all your life. We would think that it's very strange, very limited, very silly. So these people, in which I think I include myself, they think that, 'Okay. We'll have to open doors and windows. We'll have to go and see other rooms' — not necessarily to populate, but at least to explore, so that they know how, how the universe is. What it is like to be on the moon. What it is like to see the Sun as a star, to travel to other stars, exoplanets, and so on."

Esko Valtaoja

"We have not accepted space as part of our everyday life as yet, which also shows that we have not been thinking enough of this, how to really behave in ordinary life in space. How to have a circular economy, how to put everything together, how to live in an uncontrolled sustainable peaceful manner and so on. These, here on Earth, are everyday problems and concepts. But they have not been really transferred into space as yet."

Esko Valtaoja

Motivation to explore, study our environment is within human nature. One of the interviewees gives a metaphor of a person in a house and how natural it is to explore our living environment. However, what makes up our environment? The "Earthrise" photo gave humanity at large the first look at our home planet Expanding our perception of the reality we live in, which created a significant shift in human find of our home planet Earth. However, space has not been widely accepted as an everyday living environment, hence not too many concepts have yet been transferred to the space environment.

Humane aspects

"I think space ethics also will be about growing up more and more, realising things that unite us, and forgetting the things that divide us. Because in space, they don't really matter anymore."

Esko Valtaoja

"As we do this sort of thing — that it's not about planting flags, or national symbols, and all these places — that we actually approach it as one humanity, like, not every country will be able to contribute resources."

Moriba Jah

"Making it less of a nationalistic thing and more of a humanity thing, I think is the right way to do it."

Moriba Jah

There has been discussion on the values with which space activities should be shaped. That is very much about humanity, recognizing and remembering what it means to be human and acting from this standpoint. Remembering that we are one human race, in our home Earth, travelling through the vastness of space among the other planets and space objects.

What space needs

"Let's just say, for a sustainable human life in space, I think it requires cooperation, cooperation, and cooperation."

Esko Valtaoja

"I think there's a recognition that this is a shared domain, and that it's possibly a cooperative approach that is needed. Because no one country has the resources, or, frankly, the technology to be able to do it alone."

Victoria Sampson

"So we really need the development of some kind of ethical system, which allows us to give other planetary landscapes and other kinds of environments some rights to exist."

Alice Gorman

"I think that looking at issues like traditional ecological knowledge from indigenous people is important, because there are some principles regarding sustainability that I think could help inform us on how we should behave in space."

Moriba Jah

"You can't manage what you don't know. You don't know what you don't measure. So, measurements are foundational."

Moriba Jah

Ways to actualize the values discussed have been very diverse, including the increased effort on measurements, de-orbiting, embedding sustainability principles in the mission design (Design For Demise), traditional ecological knowledge, improved policy making process and cooperation. It all comes to a conclusion that there is no one solution for all, however a holistic approach to aim for sustainability. Expert opinions are offering some directions and ways for implementing that.

Scenarios

This chapter describes the future scenarios developed in this study, providing the narratives, key events, and illustrations.

Scenarios

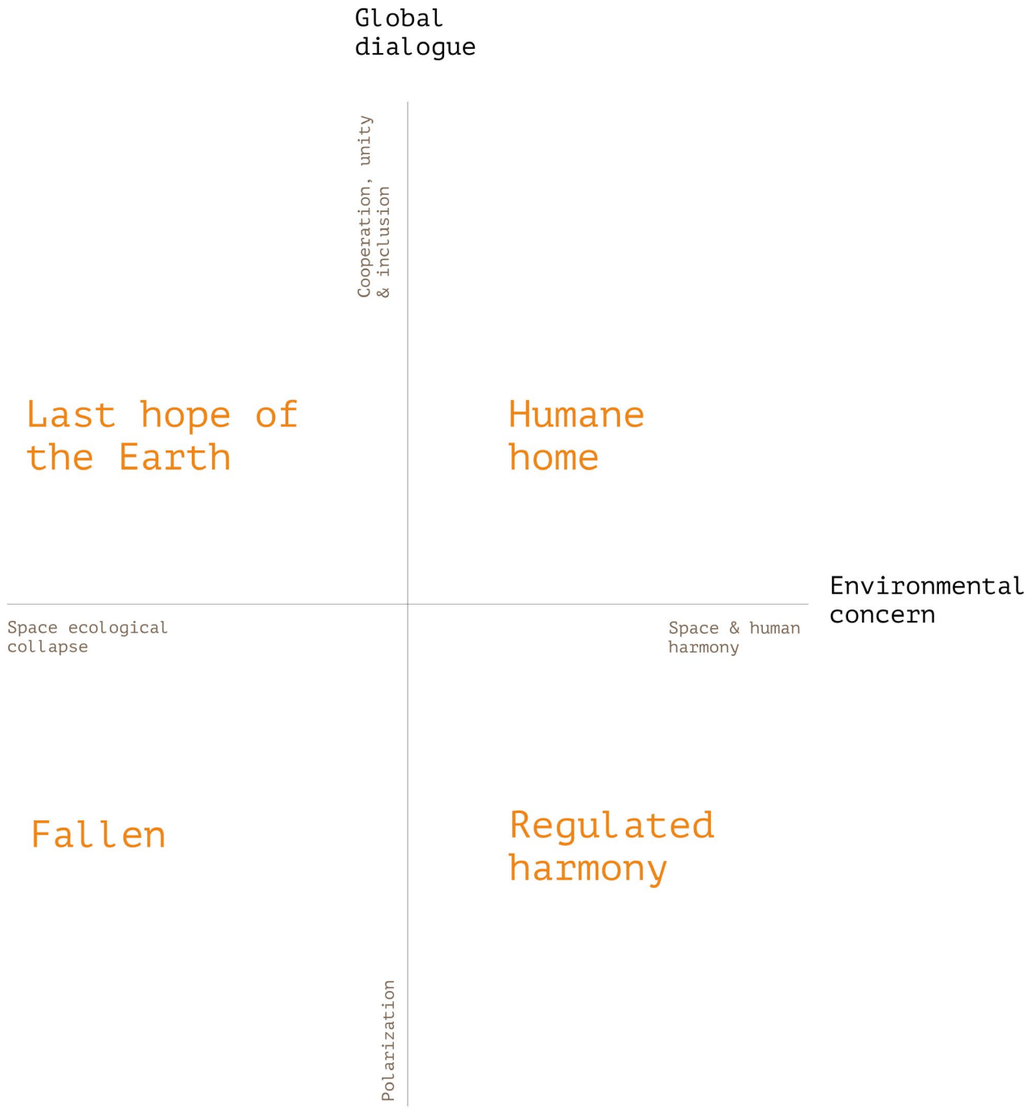
The primary objective of this study has been to develop future scenario material that could evoke discussion on sustainable futures of space among the space industry community and the general public. This chapter describes and discusses the outcomes of this study, which include four different future scenarios.

The scenarios have been developed based on a wide range of insights gained in the research providing the impetus for the narratives. During the process, there have been identified two critical uncertainties as following: global dialogue and environmental concern. Those two aspects have been very much dominant in the expert interviews when sharing the perception of the sustainable space concept and the current issues in regard to it. The way those factors evolve in the future could potentially be critical on the environment and human activities in LEO, thus it has been chosen as the scenario axes.

Scenarios are based on the following axes:

Global dialogue - describes the atmosphere and the way space domain actors are related to each other, the level of dialogue present in the community. On one end is a community that is polarized and is not being able to make the decisions, the goals of the community are dispersed, often opposing each other. On the other end is a community that is tied together by a sense of unity. The community is cooperative, inclusive, and working for the bigger goals.

Environmental concern - describes the state of the space environment, LEO orbits, and the human relation to it. On one end there is a space ecological collapse, an environment that has been critically disrupted, affecting as well the environment on Earth and the ability to operate in LEO. On the other hand, there is space & human harmony, the environment which orbits are in balance, respected, and safe.



Humane Home

Cooperation, unity & inclusion - Space & human harmony

The realm of space has become the extension of our natural home. We explore, we observe, we admire the vastness of space. We see natural stars that are thousands of light years away. And yet, we have also created our own stars, so much closer at about 800 km above us. They are reminding us of our species - one big family of Homo Sapiens who have enveloped the Earth in layers of the orbiting satellite constellations. These orbits are our new roads, carrying traffic thousands of times faster than our electric vehicles on the ground. The precision of traffic choreography is achieved by the global states cooperation to build the interplanetary consciousness. Keeping these orbits harmonious is now an integral part of human life.

It has taken extreme efforts and sacrifices to stabilize the World's climate. Earth's climate will never be what it used to. But we have learnt. We don't want the same mistakes to be repeated. Thus, sustainability is our engine for survival. All space missions are designed under the principle of Design For Demise (D4D) with deorbiting capacity. Missions are ranked by points of sustainability that evaluate various aspects of the satellite and the mission such as materials, ability to monitor satellite position, ability to deorbit, social conditions of the workforce and other aspects.

Due to its accessibility, most space missions take place in the low orbits. High demands call for careful management of orbital slot availability. Thus, after mission completion, satellites are moved to lower orbits to let them naturally burn. Advances in material science have succeeded in ensuring that parts will not survive the atmospheric re-entry and reach Earth's surface.

NGOs have been established in nations that have difficulties to contribute economically. Those are seeking to build space literacy, enable communities to access space technology provided services, and hear the community views. Greenland has a satellite gifted by South Africa and named for Savissivik, a location known for its meteorites in Greenland. This generous gift from South Africa is inspiring young generations to pursue education in space science and technology.

Open data sharing has been a vital key to successful LEO traffic management. Companies have learnt from the case of Earth, when indifferent handling of information has led to disastrous results. Space is recognized as one of humanity's common resources, open to everyone, and open data sharing, which respects the debris mitigation guidelines and takes care of the allocated orbital slot, is a space operator's ticket to space, for the poor and the rich alike.

Scenario in a nutshell

Our home. There is a global understanding of space as the extension of our Earthly home and the need for treating it with respect.

Cooperative community. Cooperation in taking proactive decisions towards sustainability; increase in the public-private partnerships.

Embedded sustainability in the mission design. Environmental impact measures, Design for Demise (D4D), respect to space debris mitigation and UN COPUOS LTS guidelines embedded in the mission design.

Unity of space. There is meaningful inclusion of indigenous communities and nations of lesser financial capacity in the dialogue regarding the utilization of space.

Sustainability as a must. Sustainability is no longer considered simply as a competitive edge, but as among the first and foremost requirements.

Trust and transparency. Organizations understand the crucial importance of the open data sharing of the mission for space traffic management, and are proactive in doing this.

Space flea market. Circular economy principles are actively applied to space activities. Trust among space operators allow for effective in-orbit servicing.

Regulated Harmony

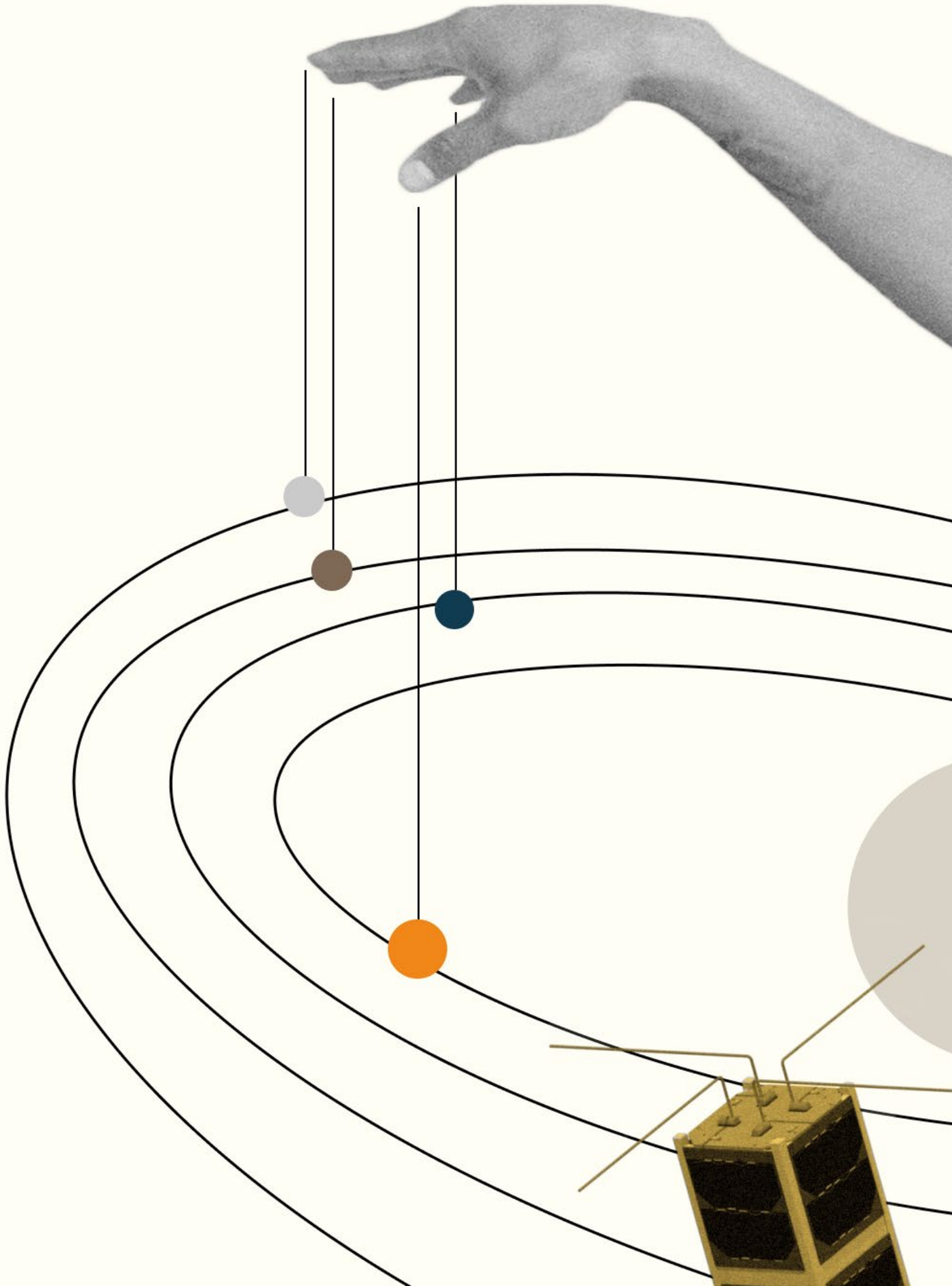
Polarization - Space & human harmony

Space environment in LEO is in harmony. New binding regulations have been a key to finally achieve this. Widely disregarded space debris mitigation guidelines have been replaced with new binding regulations that are actively implemented. However, not all space operators could afford to adapt to these new changes. Some have experienced technical or economical challenges and had to change scope of their work or even leave the domain. This creates a situation where in practice only a handful players, dominated by a small number of nations, act as decision makers in the field.

New regulations have increased the demand for sustainability solutions in the space domain, thus, creating an uptick in efforts developing sustainable technologies around the world. Independent inventors and technology centers alike are focussing their efforts on sustainable space technologies. Advancements in sustainable technologies become a signal of leadership. However, polarized global political situations prevent potential collaborations, stymying the work of the space science and technology community.

Open data sharing of satellite location is demanded by law. This finally helped to achieve successful space traffic management, maintaining a safe space environment. Space law has been on a rise. The behaviours of actors are being discussed as legal or illegal.

A new concept of “space citizenship” starts to take hold, as permanent and long term human occupation of orbital stations become commonplace. Legal issues require a new framework as different nationalities are becoming directly affected by the commercial industrialization of space. The issues of space dividends start to become potential flashpoints, politically and economically.



Scenario in a nutshell

Rise in space law. Behaviours in space are discussed as legal or illegal. Decreasing number in new missions and space operators, who cannot manage to comply with the binding norms.

Evolving understanding of the environment. Planetary boundaries concept updated to include the space environment. New sets of SDG include direct attention on LTS of LEO.

Space citizens. Life on the spaceship Earth and beyond. Humans exploring their living environment.

Strive for your own good. Satellite operators demanding for their rights to exit from the altitudes that are layed with debris.

Sustainable technologies adopted. Plasma brake, propellantless way of travelling E-sail, reusable space rockets are fully adopted becoming a norm. New developments on materials to find good alternatives to Titanium.

Transparency achieved. Transparency of space activities achieved after introducing binding legislations on the open mission data sharing.

Green actors stay. Decreasing number in new missions and space operators, who cannot technologically or economically comply with the new binding norms.

Preference for Low orbits. Increase in low orbiting satellites.

Fallen

Space ecological collapse - Cooperation, unity & inclusion

Human greed has made LEO into the Wild West of space. Private entities have built a capacity to access and operate in the orbits, and now is the time to get most out of it. Space enabled services on Earth are constantly being improved in accuracy and accessibility. However, that happens at the cost of overcrowded orbits. Operators are launching large constellations with little consideration to the environment and new missions to be launched. Satellites at the end of the missions are just abandoned. Many are just left orbiting for decades and centuries disregarding the space debris mitigation guidelines.

Nations see the economical potential in hosting space operators. Thus, “flags of convenience” a principle seen in the maritime industry emerges. Nations compete creating legislative and taxation frameworks that attract the space operators to operate under their flag. Such governance creates even higher economic inequality compared to what it used to be.

Crowded space activity in LEO is heavily disrupting visibility of astronomical observations. There are plans for building new space based observatories. However insufficient funding is challenging those plans, making a whole generation of scientists trapped with disrupted sky visibility.

General public loses patience. A few weeks prior, space debris took the life of a youngster living in the suburbs of a densely populated area, while seriously injuring a few others. This is the second such fatal accident in as many years. Legal loopholes mean that no one can be held responsible, just pointing fingers to the governors, and governors pointing to the operators. People ask for justice, demanding technologists to take the responsibility. Furthermore, drastically increased inequality, makes it very challenging for the poorest to live, afford education, medical care and other basic needs met, after the inflation skyrocketed. Protests keep happening.

Having low trust in the space industry, activism in environmental and social causes concerning space activities in LEO takes place. Equal space for everyone - is the hope of this generation.

Scenario in a nutshell

Wild West in space. Space operators act without much consideration on others and the environment.

“Flags of convenience”. System that “legally allows” space operators to seek for claiming national benefits. National legislative frameworks as tools for becoming a space faring country.

High economic inequality. Benefits obtained from space are distributed disproportionally creating a very high economic inequality among the nations.

Threat on Earth. Orbital debris reaching Earth causes serious risks for the human life and Earth environment.

Fragmented international community. Competing national interests make it very challenging to achieve common agreements on how the space environment should be managed. There are occasional efforts to involve all the stakeholders in the development of new binding regulations. However, most turn out to be unsuccessful, or to be mostly symbolic in practice.

Low trust space. People on the Earth have lost trust in the space industry due to its low transparency, disrupted services, dual-use of the missions and a recent accident on Earth compromising the safety of the human and living environment.

Space environmentalism. Growing interest of the general public in space environmentalism. Growth in citizen science.

Last Hope of the Earth

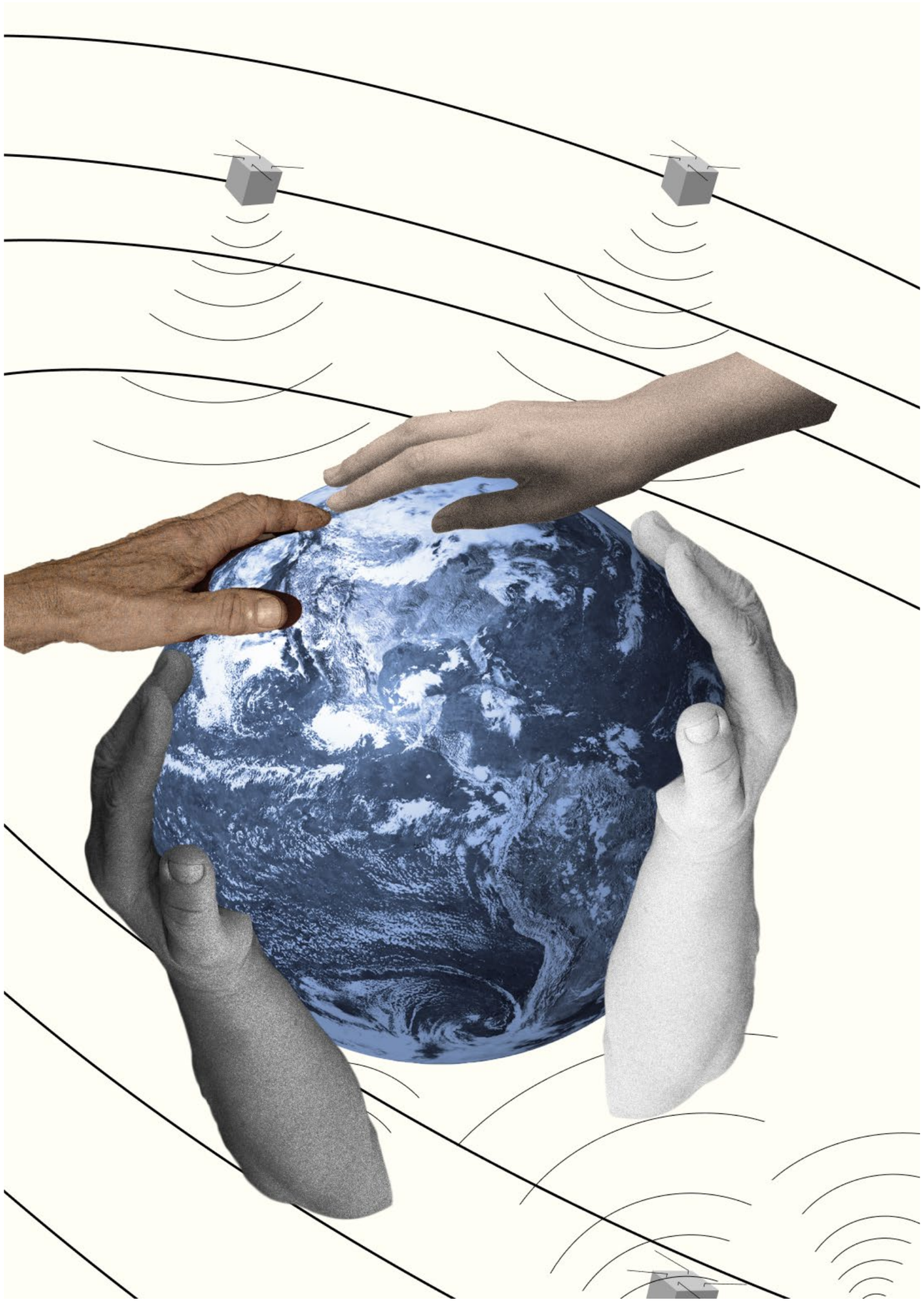
Polarization - Space & human harmony

Earth is in an emergency and the global community finally agrees on that. However, agreements and words are not enough. There is a need for action, urgent action. Space science and technology community co-operates in saving the Earth. Space missions are concentrating on Earth observation, providing 24/7 live Earth observation data. Furthermore, scientists are actively developing ways on energy production in space to support the Earth. Reductions from space science funding are allocated on climate emergency actions.

Humans understand that planetary boundaries have been crossed and that there is no way back to what life on Earth used to be. Unbearable heat and destroyed ecosystems is the reality. Hope? People used to talk about hope, probably even for too long. Global “Save the Earth Alliance” is established. In this alliance only actions speak. The progress is measured and announced on daily news.

Scientists are treated with the highest respect and listened to by the governments and community. They have measured that it will take several generations to make an improvement and in our lifetimes we probably won’t feel it. However, humans’ new consciousness and intrinsic motivations to do good are leading the way. Homeland, nature surroundings, food - Earth has been providing us perfect conditions to flourish. And we humans? We went on the path of destruction.

Recognition of space as our extended homeland makes us wonder how not to repeat the mistakes we have done on Earth.



Scenario in a nutshell

Hope for the Earth. Climate crisis issues take the public attention from the worsening LEO condition. Space becomes a hope for solving the issues on Earth by providing new sources of resources and environment for habitat.

Intense monitoring. Earth observation missions are dominant to monitor the critical condition of Earth. Other space activities are being pushed to the background. Real-time surface monitoring is available 24/7. Live video monitoring the Earth surface available 24/7.

Global "Save the Earth Alliance". Global alliance is established to coordinate the multi-generational action plan for saving the habitability of our planet. Among them is an in-orbit energy generation.

The call for indigenous knowledge. Indigenous communities are finally being heard, and are able to share the thousands of years old knowledge and principles on environmental sustainability, which become the basis of global conventions.

Climate refugees. Large scale migrations to the cooler zones on the Earth. Local conflicts with native populations demand stronger global cooperation.

Policy reflection

This chapter describes what implications each scenario could have on the policy development process.

Policy Reflection

The four scenarios described have varying interconnections to the current and new policies to come. This chapter describes what could be the impact of each scenario on the policies concerning space activities in the LEO.

Humane Home
In this scenario policies predominantly remain effective on a voluntary basis. The increased environmental consciousness of the space operators makes the guidelines effective, without a need for stricter regulations.

Regulated Harmony
In this scenario, voluntary guidelines transform into binding regulations. Decision-makers share the understanding of the need for long term sustainability for space activities. A shared understanding of the most pressing issues in LEO makes it possible to introduce new binding regulations and legal frameworks.

Fallen
In this scenario, the pace of space activities is very fast with little concern on the space environment. This puts pressure on the decision-makers on the need to ensure the safety, security, and long term use of the space. However, the lack of international agreement makes it hardly possible to develop legislative tools. Space activities in LEO remain loosely regulated.

Last hope of the Earth
In this scenario, decision-makers introduce high incentives on the missions focussing on the Earth Observation (EO). The regulatory framework of space activities has been in active development continually. Thus, it is rather effective in maintaining sustainability in LEO. However, the focus of space activities, legislative frameworks, and funding is very much focussed on mitigating the climate crisis on Earth.

In conclusion, Humane Home describes an ideal situation, where there is a shared understanding between the decision-makers and the space operators. Regulated Harmony scenario achieves the desired goals of sustainability in LEO as well, however, this comes by putting a higher burden on the space operators to comply with the new regulations. The worst-case scenario in terms of policy-making is Fallen, where there exists a rather chaotic situation on both sides - space operators and policymakers - where dialogue is very rare. Finally, Last Hope of the Earth aims to maintain space activities in LEO moderately regulated, with high incentives and priority on the Earth Observation missions.

Discussion & conclusions

This chapter opens up the discussion on findings and opportunities for the future research concluding this research study.

Discussion

This study applies a systematic approach of CLA to study the underlying values of human activities in space that are further transferred in future scenarios. This is rather a novel approach in the emerging field of space sustainability research.

The study recognizes the need for dialogue in the space industry community. The question comes where such dialogues should and could take place? Is it at the UN, or should there be different forums that are open to anyone? How do we involve countries that do not have the economical capability to be active in space activities? These are just some of the questions that the author raises with this work.

Another important question is how do we make sustainability actionable in the space domain? This study recognizes the need for holistic solutions. However, how do we make it happen? The author recognizes the following directions:

- A long path of building consciousness on how we want as humanity to approach the space, a bottom-up approach,
- A short term solution through introducing binding regulations, a top-down approach.
- A combination of both. Regulations that encourage grassroots movements.

CLA solutions often result in consciousness transformation, in changing worldview, in rethinking politics of reality (Inayatullah, 1998). Thus, this study works as well as a test base on how such discussion material would be perceived by the space science and technology community.

Project Humane Orbits offers probes for discussion. For the future research, author would like to develop a workshop toolkit for discussing sustainable futures of space, both for internal teams of space projects, as well as large forums of diverse stakeholders.

Conclusion

This scenario planning thesis study on sustainable space futures has resulted in four transformative futures scenarios that serve as discussion prompts. It has been recognized that there is a need for holistic solutions to address the sustainability of space. This could range from inclusive discussions on the values with which space domain activities are being shaped, to proactive actions of space operators

(e.g., open data sharing, implementation of Design For Demise in the mission design, de-orbiting), with great focus on research and development of sustainable technologies.

CLA has shown that in order to aim for sustainability, there should be a shift in the values toward approaching space with a more humane perspective, as opposed to greed and power. This is a very deep-rooted issue, which may take decades if not centuries to transform. However, our generation could think of seedlings we can plant in our lifetime to support this transformation.

Finally, our human understanding of space is constantly being shaped. This study has shown emergence in the views perceiving space as extension of our Earth environment, even as the living environment if we consider the International Space Station (ISS). This could potentially bring shifts in sustainability science, and what we perceive as our living environment, as well as how humans perceive being part of space.

> *"it's space change us. It changed already. We are living in the middle of it so you cannot really see ourselves in the middle of that how space already has changed us. But it's space is waiting for us. And I think it's said, as the actual manifest destiny of space."*
> Esko Valtaoja

Limitations

This study has limitations on multiple levels, including the research process and final outcomes delivery. The limitations are further described in this chapter.

Space sustainability is a complex issue, demanding space domain-specific knowledge in order to be able to meaningfully apply sustainability science perspective. This challenge has been approached by the author by immersing in Space Science & Technology domain studies for one year at Aalto University. The studies have helped to build the initial foundation for understanding the space domain, and the current discussions. It has shown how multifaceted subject it is.

Scenario planning methodology, being suitable for studying uncertain contexts, may also have some limitations in such contexts. According to Hodgkinson and Wright (2002), scenarios may cause "dysfunctional stress levels" for its readers, the decision-makers, when future cases are seen as too difficult to address. The author suggests that scenario planning and similar methodologies could be applied in the space domain in the long-term, eventually building capacity to work with such tools.

Practical limitations, such as time, have had a large impact on the scoping of the thesis research. After developing the final scenarios, initial commentary meetings have been set up. Ideally, the author would like to test it in a workshop setting or a conference forum. Furthermore, during the process, ideas on the project directions and potential continuation emerged, which the author would like to continue after the thesis.

The fact that the thesis was done during the pandemic, with the research done remotely, the option of on-site workshops or interviews could not be considered. In the early stage, it had little effect, although, the research outcomes could not be tested in a face-to-face setting, for which it was initially developed.

The technical nature of the subject may be challenging to involve the general and more diverse interviewee group. Thus, at this stage, the author has interviewed only experts, with plans to approach the general public using the outcomes as prompts for discussion. This would hopefully involve much more diverse stakeholders, and it would avoid the situation that the outcomes are being shaped only by the ones with privilege.

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List of Figures and Tables

Appendix

List of the interviewees

	Name	Occupation	Affiliation
1	Adriell Amor	Young graduate; Areas: asteroid mining, sustainability	Aalto University, FI
2	Alice Gorman	Space Archaeologist	Flinders University, AU
3	Anne-Marlene Rüede	Space Safety and Sustainability Project Group Co-Lead	Space Generation Advisory Council, AT
4	Christian Frei	Documentary movie Space Tourists director	Christian Frei Filmproduktion GmbH, CH
5	Esko Valtaoja	Astronomer and writer	University of Turku, FI
6	Jaan Praks	Assistant Professor; Areas: Space technology, Microwave Earth Observation	Aalto University; Finnish Centre of Excellence in Research of Sustainable Space, FI
7	Moriba Jah	Astrodynamicist and space environmentalist	The University of Texas, US
8	Pekka Janhunen	Space physicist, astrobiologist, and inventor	Finnish Meteorological Institute, FI
9	Shashikant Gupta	Young graduate; interests: astronomy	SpaceMaster program
10	Stefan Kirchner	Associate Professor of Arctic Law; Lawyer; Areas: Arctic Law, Law of the Sea, Human Rights, Safety, Marine Environmental Law, Environmental Human Rights	University of Lapland, FI
11	Victoria Sampson	Washington Office Director for SWF; Areas: military space and security issues, policy	Secure World Foundation (SWF), US


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Aalto University